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FINAL REPORT

6 Investigation of  
Shielded and Unshielded Cables.

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Contract N00173-79-C-0129

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1.0 ABSTRACT

The mechanical properties of shielded and unshielded submarine cables (MIL-C-915/8E) were investigated to determine the effect of shielding on cable life, performance and reliability. Ten cables, five shielded and five unshielded, were selected for laboratory evaluation. A mission profile was developed to establish the mechanical stress limits cables must endure in service and a test sequence designed to measure tensile strength, flexural abrasion endurance, crush resistance, creep under static tension and performance in a hull stuffing tube.

The results of this program showed the following:

1. DSS-2 cable does not have adequate tensile strength and should have a strength member added. DSS-3 and larger cables have adequate tensile strength with and without the shield.
2. Unshielded DSS-3 type cable does not perform satisfactorily in hull stuffing tubes.
3. Shielding is not required to meet Mission Profile specifications for cable crush or flexural abrasion resistance.
4. Construction parameters other than shielding can significantly affect mechanical performance of cable.
5. Unshielded cable construction can result in increased reliability since it permits a thicker single jacket construction.
6. Unshielded cable construction can reduce the cost of cable by 8% to 20%.

## 2.0 BACKGROUND

This report covers the work performed on Phase I of Contract No. N00173-79-C-0129, "Investigation of the Strength of Shielded and Unshielded Cables." This contract was awarded to Texas Research Institute, Inc. (TRI), in May, 1979, and was awarded as part of the FY79 Sonar Transducer Reliability Improvement Program (STRIP).

The STRIP Program investigates problems of current interest to the fleet. An objective of STRIP is to provide engineering solutions to problems that improve the life and reliability of sonar hardware. Underwater cables, an essential part of wet-end sonar hardware, have a history of failures which result in premature sonar replacement. Therefore, any improvement to cables lessening the frequency of failure would improve the reliability of the attached sonar hardware.

Puncture of the cable jacket is a known failure mode and has been identified in General Dynamics/Electric Boat Division Report No. U 443-78-036 as the most probable cause of cable failure. The jacket on shielded cables is relatively thin and can be easily punctured to the shield. A jacket puncture to the shield results in flooding of attached connectors, degradation of electrical properties and loss of the sonar transducer. As reasoned, constructing cable without the shield would provide a thicker, more puncture resistant cable less susceptible to premature failure.

The strength requirement of cable and the mechanical contribution of shielding to tensile strength, abrasion and crush resistance have been arguments for retaining shielded cable construction. Unshielded cables have had only limited use in the fleet, and data confirming unshielded cable mechanical performance have not been available.



## 3.0 APPROACH

The objective of this investigation was to provide quantitative data to compare the mechanical properties of shielded and unshielded cables, determine how these cables are used and what mechanical properties are required for use, identify failure modes for the cables under stress and provide an analysis of the cost and reliability tradeoff of shielded and unshielded cable.

To meet these objectives a three task laboratory program was designed as shown in Figure 1. The first task compiled background information on cables and resulted in a detailed Mission Profile description of cable exposures through all phases of cable life, procurement of samples of ten cable types for comparative testing, and a test plan consisting of six mechanical tests. The second task exercised the test plan using the sample cables. Task 3 analyzed the resulting data and compared test values to service requirements.

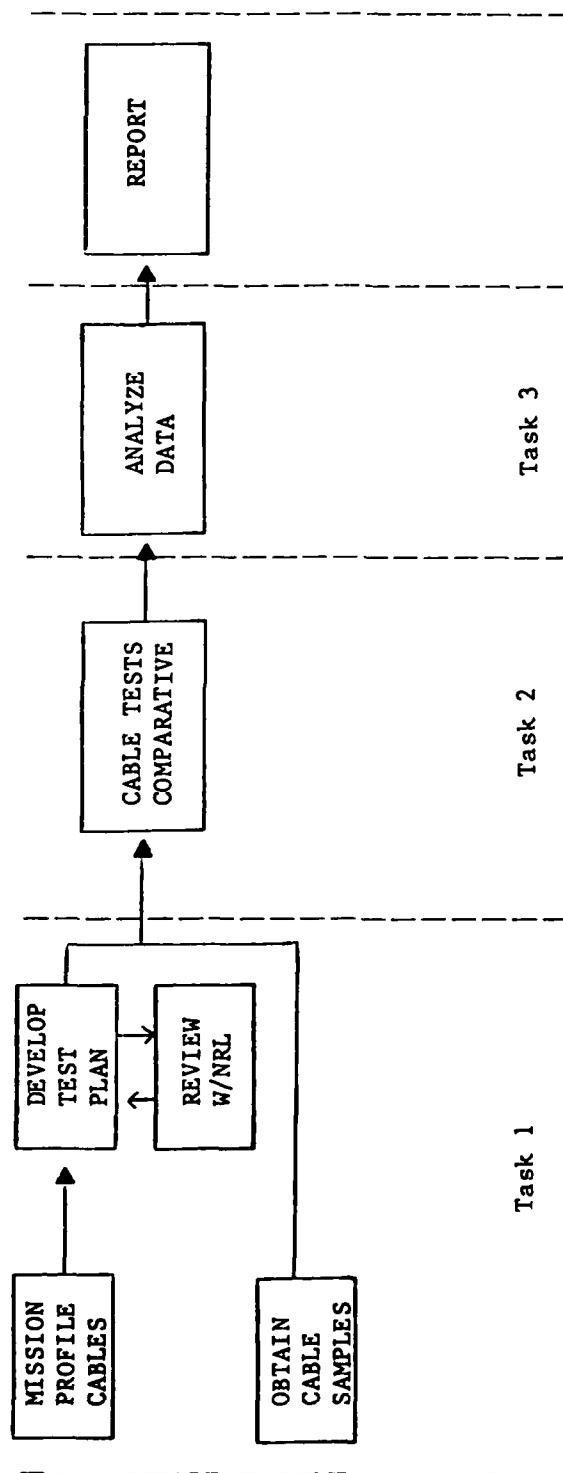


Figure 1. Flow Chart - Phase I, Cable Evaluation

#### 4.0 DISCUSSION OF RESULTS

Four specific questions have been addressed in this project and are:

1. What forces do cables experience during installation, ship operations, and maintenance?
2. Does the shield provide additional tensile or crush strength and resistance to cable failure?
3. Does a shield provide any protection from puncture or does it contribute to failure by abrading and puncturing the insulation?
4. What is the cost and reliability tradeoff of shielded versus unshielded cables?

The following discussion addresses these questions and proposes solutions to identified problems.

#### 4.1 Mission Profile

Two divisions of the Mission Profile identify mechanical stresses to cables. The most strenuous exposure occurs during Installation and Maintenance and less strenuous, but longer term exposure occurs in Service.

Tensile stress occurs in both areas. Examination of installation and maintenance requirements shows that developed stress is dependent on cable type because of the difference in weight of the cables and the weights of an attached transducer. Independent of cable type is the possibility of a cable used as a hand hold by maintenance personnel and thereby supporting the full weight of a person, approximately 880 N. Although the DSS-3 Profile does show a maximum weight of 1960 N, when attached to TR-232 transducers, cable exposure to this value is unlikely since the conductors would break and detection would be obvious. Reports from the fleet have not been made of this excessive stress. More typical attached weight is approximately 240 N and hand hold occurrence of 800 N is the most probable maximum tensile stress cables will see.

Long-term static tensile stress is a result of an unsecured vertically suspended length of cable. Shipboard cable installations are designed to be secured in cable trays and an unsupported cable run is not likely to occur. In the event an unsupported condition would exist, the resulting tensile load for 30 m of DSS-3 cable would be 70 N less than the overriding maintenance hand hold exposure.

Impact, crush and flexural abrasion and compression squeeze are the remaining mechanical cable stresses and occur during installation and maintenance. Impact and crush values are identical between cable types, resulting from dropped tools, pinching in cable trays, foot traffic and similar abuse. Stress levels for impact and crush were extracted from Underwriter's Laboratory Standard 44, and as this standard has been accepted by industry as describing practical endurance limits, are the levels recommended for cable specification. Flexural abrasion exposure and the accompanying flexural stress occurs during installation and the stated values are an approximation of maximum forces encountered due to cable installation in or over conduits. The reported exposures were determined by combining maximum tensile stress with a typical bend radius of 25 m.

Table 1 summarizes the maximum mechanical stresses as identified in the Mission Profile for cables during installation, ship operations, and maintenance.

#### 4.2 Strength Contribution of Shields

The tensile results of whole cables shows that shielding contributes 15% to 18% of the strength of DSS-2 cable and 24% of the strength of DSS-3 cable. Comparing Butyl Size 3 cable to DSS-3 shows the shielding contributing 32% of overall strength. However, shielding does not increase the yield strength of cables.

Table 2 lists the required and measured strengths of the test cables. Both shielded and unshielded Size 2 cables do not meet the strength requirements for

TABLE 1  
CABLE STRESS LIMITS

EXPOSURE	CABLE TYPE			
	DSS-2	DSS-3	DSS-4	FSS-2
Tensile N	880	1960*	880	880
Crush N/50 mm	5290	5290	5290	5290
Impact N•m	2	2	2	2
Flexural Abrasion Load (N) Over 50 mm Mandrel	255	1960*	490	862

\*Load for TR-232 system only.

TABLE 2  
CABLE TENSILE PERFORMANCE

Cable	Tensile (N)		Yield (N)
	M.P. <sup>1</sup>	Test	Test
DSS-2	880	620	390
DSU-2	880	500	390
DSS-3	1960 <sup>2</sup>	1120	660
DSU-3	1960 <sup>2</sup>	860	640
Butyl-3	880	760	550
DSS-4	880	1540	1040
FSS-2	880	1320	840
TRIDENT	880	800	620

1: M.P. = Mission Profile requirements.

2: Stress Requirement for TR-232 only; other systems require 880 N.

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the 880 N hand hold maintenance requirements and would break under this load. The DSS-3 exceeds the 880 N requirement and the DSU-3 is within 20 N of meeting this load. The 880 N hand hold requirement is a high estimate of the weight of maintenance personnel and average exposure would likely be less than this value. Both DSS-3 and DSU-3 can, therefore, be expected to survive the exposure.

Full loading by heavy transducers, 1960 N for DSS-3 although possible, is not likely to occur. Use of cables as a handle to lift transducers does frequently occur but the lifted units generally weight less than 240 N. Cables used as a hand hold during maintenance with the resulting 880 N load is likely to occur and should be considered in cable design and as a valid exposure limit.

Table 3 itemizes the strength contribution of the cable components. In all cables the conductors were a major strength component. However, for the TRIDENT cable the polyethylene insulation contributed 29% of the cable strength which exceeds the 25% strength contribution of shielding for DSS-3 and FSS-2 cables. Also, the Butyl cables showed 9% strength contributed by the insulation materials. DSU-3 cable, a similar construction to that of the Butyl cable, has 17% strength contributed by the belt and jacket.

It is concluded that shielding can act as a strength member and for small diameter cable such as DSS-2, a strength member is required. However, shielding alone does not provide sufficient strength for Size 2 cable and improved strength members should be considered. For DSS-3 and larger cables, shielding or other strength member is not required to prevent cable breakage. Insulation materials can add to tensile endurance as exhibited by the TRIDENT polyethylene cable and lessen endurance as in the Butyl Size 3 cable.

#### 4.3 Crush Resistance

The obtained data for cable crush characteristics shows that shielded cables DSS-2 and DSS-3 are 7%-15% more resistant to crush failure than a DSU

TABLE 3  
CABLE COMPONENT STRENGTH CONTRIBUTION

Cable Type	Strength Contribution (%)		
	Insulated Conductors	Belt and Jacket	Shield
DSS-2 Unshielded	89	11	none
DSS-2	67	16	17
DSU-2	88	12	none
DSS-3 Double Jacket	61	15	24
DSS-3 Single Jacket	62	13	25
DSU-3	83	17	none
DSS-4	77	5	18
FSS-2	68	7	25
Butyl Size 3	91	9	none
TRIDENT Polyethylene	71	29	none



type cable. However, all measured cables with the exception of the DSS-2 Special Unshielded, and the Unshielded Butyl Size 3 survived crushing forces in excess of the mission profile limit of 5300 N/50 mm length. The unshielded TRIDENT polyethylene cable was approximately four times more resistant to crush than the elastomeric shielded cables and ultimately failed with an open circuit rather than by shorted conductors. This again indicates that properties of the cable insulating materials can add to or detract from the crush resistance of cables more than shielding.

It is concluded that shielding is not required for protection from crush damage. Also, increased crush resistance can be obtained, if required, by selecting tougher materials for insulation such as that used for the TRIDENT polyethylene cables.

#### 4.4 Cable Puncture Resistance

Cable puncture was not found to be a result of conductor wire or shield wire breakage. The flexural abrasion test did fatigue shield and conductor wires to failure but electrical measurements made during the test did not show degradation of insulation resistance or shorting to ground or between conductors. The failure mode identified during the crush test was conductor-to-conductor shorting. Jacket or primary insulation puncture by the shield was not found to be a failure mode.

Puncture of the cable by external forces was not investigated in this program. Shielding can be expected to inhibit cable puncture to the conductors by external forces; however, once the jacket is punctured to the shield, water ingress along the shield will occur and the cable will fail at the connector.

It is concluded that shielding does not contribute to internal puncture related failures and can only delay and not prevent failure from external puncture.

#### 4.5 Hull Stuffing Tube Results

As shown in Table 4, three of the four samples of unshielded cable (DSU-3) moved over 6 mm during the pressure cycling, and all four of them continued moving at each cycle. The shielded cables moved less than 2 1/2 mm in the test series, and appeared to become set after two pressure cycles and thereafter move little or none.

#### 4.6 Cost and Reliability

Complete cost data for unshielded cables is not available from manufacturers since DSU cable is not routinely made. Removing the shield results in a considerable manufacturing time savings in cable assembly and could also delete the requirement for double jacket. Estimates of the cost savings by shield removal of 8% to 20% have been made by cable manufacturers.

Impact of shield removal on the reliability of cable varies with failure mode and cable size. The most likely failure mode identified in the GD/EB report was puncture of the cable jacket. Since internal puncture was not found in the test program, puncture from external causes is the mechanism of concern. Shield removal would provide as much as 150% thicker elastomer puncture barrier in DSS-3 cable than is presently available. The probability of external puncture to unshielded conductors would be less than the probability of puncture through the jacket only. Shield removal would appear therefore to increase cable reliability.

Considering the small size 2 cables, shield removal would increase the probability of failure due to tensile stress. Size 3 cables are not as affected in a tensile failure mode and the reliability impact of shield removal would not be significant.

The TRIDENT cable demonstrated superior performance in tests of flexural abrasion and crush, and typical performance in the other areas tested. It

therefore appears to be a highly reliable cable; the reliability of cable assemblies using this material is most likely to depend on the reliability of the terminations.

TABLE 4  
HULL STUFFING TUBE PERFORMANCE SUMMARY

SAMPLE NUMBER	CABLE TYPE	INITIAL			CYCLE 1			CYCLE 2			CYCLE 3		
		IR Ohms	CONDUCTORS	IR Ohms	CONDUCTORS	MOVEMENT (mm)	IR Ohms	CONDUCTORS	IR Ohms	MOVEMENT (mm)	CONDUCTORS	IR Ohms	ACCUMUL. MOVEMENT (mm)
1	DSS-3	>100G	Good	>20G	Good	1.78	>20G	Good	>20G	2.41	Good	>20G	2.41
2	DSS-3	>100G	Good	>1G	Good	1.14	>1G	Good	>1G	1.40	Good	>1G	1.40
3	DSS-3	>100G	Good	>100G	Good	1.45	>30G	Good	>30G	1.85	Good	>30G	1.91
4	DSU-3	>100G	Good	>100G	Good	22.48	>100G	Good	>100G	--	--	--	--
5	DSU-3	>100G	Good	>100G	Good	6.68	>100G	Good	>100G	--	--	--	--
6	DSU-3	>200G	Good	>100G	Good	1.78	>100G	Good	>100G	3.56	Good	>100G	3.81
7	DSU-3	>200G	Good	>100G	Good	1.47	>100G	Good	>100G	17.14	Good	>100G	18.03

## 5.0 MISSION PROFILE

A mission profile is a description of environmental and mechanical stresses to which hardware is exposed during the lifetime of that hardware. Environmental stresses include temperature extremes, thermal shock, moisture exposure, U.V. radiation, pressure excursions and other exposures that contribute to materials degradation or change in properties. Mechanical stresses address physical changes in materials caused by tensile, torsional or compressive loading, fatigue, abrasion and other similar factors.

The information developed in a mission profile is essential input to product design and to verification test design. The maximum and minimum stress exposure called out in a mission profile are used as guidelines to design and to test products for endurance to expected use. As such the mission profile is a tool for insuring product reliability and life expectancy.

For this program, the mission profile for cables was developed to provide maximum and minimum stress limits for comparison of cable types. Three categories of mission profile were established, Transportation and Storage (Table 5), Installation and Maintenance: Environmental (Table 6) and Mechanical (Table 7 through 10); and Service: SSN (Table 11), SSBN (Table 12) and Surface Ship (Table 13).

The general format used for describing the mission profile is as follows:

Column 1 - Exposure number for identification.

Column 2 - Exposure description.

Column 3 - Range of exposure, maximum and minimum values that can be experienced. This range covers all ship use.

Column 4 - Where the exposure occurs during use.

Column 5 - Time weighted description of extreme exposure reduced to one year's estimated stress, based on maximum or minimum exposure values.

Column 6 - Time equivalent of extreme exposure.

Column 7 - Time weighted description of a typical or average exposure reduced to one year's estimated stress.

Column 8 - Time equivalent of typical exposure.

Column 9 - Companion exposure that may contribute synergistically to materials changes in service.

Information contained in the mission profile was collected from various sources. Among these are product specifications, steaming data or estimates of this data, consensus opinion of Naval personnel associated with maintenance and fleet operation, published literature and manufacturers' opinions. In some instances hard numerical data for an exposure were not available and the data presented were therefore estimated.

Of the profile categories, Transportation and Storage exposures apply to all cable types. Installation and Maintenance was subdivided into environmental exposures, which apply to all cables, and mechanical exposures, which apply only to specific cable sizes. The subdivision was required because of the difference in weight and use between cables. Service profiles were also subdivided into SSN, SSBN and Surface Ship exposures because of the different mission requirements between these ship types. Maintenance schedules are different for these ship types as shown in Table 14, and influences the inservice exposure levels hardware will see.

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TABLE 5: MISSION PROFILE - TRANSPORTATION AND STORAGE  
CABLES

DURATION (Time or Cycles)								
NO.	EXPOSURE	EXPOSURE RANGE	OCCURANCE	EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	COMPARISON EXPOSURES
1	Temperature in air	-30° to +70°C	Storage Outside	70°C for 5 hrs/day x 180 days	900 hrs			Humidity Ultraviolet Air Pollution
2				-30°C				
3			Covered Storage	12 hrs/day x 30 days	360 hrs		-6° to +38°C 8640 hrs	
4	Pressure in Air	12 to 100 kPa	Air Transportation	12 kPa 2 flights x 8 hrs	16 hrs			Humidity Temperature Air Pollution
5			Storage			100 kPa	8640 hrs	
6	Humidity	-30° to +38°C Dew Point	Storage	-30°C Dew Point 30 days	720 hrs			Temperature Ultraviolet Air Pollution
7				+38°C Dew Point 120 days	2880 hrs			
8						+10 to 32°C Dew Point	8640 hrs	
9	Ultraviolet Radiation	0-2625 $\mu\text{w}/\text{cm}^2$ @ 290-400 nm	Storage Outside Uncovered	2625 $\mu\text{w}/\text{cm}^2$ 1.5 hrs/day 270 days	410 hrs			Temperature Humidity Air Pollution
10						770 $\mu\text{w}/\text{cm}^2$ 8 hrs/day x 360 days	2880 hrs	
11	Air Pollution	0-500 psia	Storage	500 psi 8 hrs/day for 3 days <sup>b</sup>	24 hrs			Temperature Humidity Ultraviolet
12						200 + 50 psi 8 hrs/day for 180 days	1440 hrs	
13	Rough Handling	Per MIL-STD-167-1c	Transportation	Per MIL-STD-167-1	1 series			

a - psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219

b - Based on Los Angeles Experience, 1975.

Ozone is major contaminant.

c - Rough handling as defined by specification due to lack of service data.

TABLE 6  
MISSION PROFILE - INSTALLATION AND MAINTENANCE, ENVIRONMENTAL  
CABLES

NO	EXPOSURE	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)				COMPANION EXPOSURES
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature in Air	-30° to +60°C	Dry Dock <sup>c</sup> Winter	-30°C for 30 Days	720 Hrs			Humidity Air Pollution
2						-11° to +11°C for 180 Days		
3			Dry Dock <sup>c</sup> Summer	+60°C for 8 Hrs/Day 90 Days	720 Hrs		4320 Hrs	
4						+11° to +39°C for 180 Days	4320 Hrs	
5	Temperature in Water	-2° to +32°C	Dockside Winter	-2°C for 90 Days	2160 Hrs			
6						-1° to +15°C for 180 Day	4320 Hrs	
7			Dockside Summer	+32°C for 90 Days	2160 Hrs			
8						+10° to +32°C for 180 Day	4320 Hrs	
9	Thermal Cycling	$\Delta T \leq 50^\circ C$	Dry Dock <sup>c</sup>	$\Delta T = 50^\circ C$ 1 Cycle/Day 90 Days	90 Cycles			Humidity Air Pollution
10						$\Delta T = 30^\circ C$ 1 Cycle/Day for 180 Days	180 Cycle	
11	Humidity	-30° to +38°C Dew Point	Dry Dock <sup>c</sup> Dockside	-30°C Dew Point 30 Days	720 Hrs			Temperature Air Pollution
12				+38° Dew Point 120 Days	2880 Hrs			
13						+10° to +32°C Dew Point	8640 Hrs	
14	Air Pollution	0 -500 psi <sup>a</sup>	Dockside and Dry Dock <sup>c</sup>	500 psi 8 hrs/day for 3 days <sup>b</sup>	24 Hrs			Temperature Humidity
15						200 ± 50 psi 8 hrs/day for 180 days	1440 Hrs	

a - psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219

b - Based on Los Angeles experience, 1975. Ozone is the major contaminant.

c - Drydock frequency varies with ship type.



TABLE 7  
MISSION PROFILE - INSTALLATION AND MAINTENANCE, MECHANICAL  
DSS-2 CABLE

NO	EXPOSURES LOAD	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)		
				EXTREME	PER 1 YR.	CONTINUAL LONG TERM
1	Tensile Load, Dynamic	<250 N <sup>a</sup>	Installation	250 N	1 Cycle	
2		<880 N <sup>b</sup>	Maintenance	880 N	1 Cycle	
3						240 N 1 min.
4	Impact	<2 N·m	Maintenance Installation	2 N·m	1 Cycle <sup>c</sup>	
5	Crush	5300 N/50mm Length	Maintenance Installation	5300 N/50mm Length	1 Cycled <sup>d</sup>	
6	Internal Abrasion	250 N Tension on 50mm dia. mandrel	Installation	250 N on 50mm dia. mandrel	5 Cycles	

- a - Weight of maximum cable length plus maximum attached transducer weight  
b - Hand hold support.  
c - Specified in Underwriter Lab STD 44 (Par 82).  
d - Specified in Underwriter Lab STD 44 (Par 81).

TABLE 8  
MISSION PROFILE - INSTALLATION AND MAINTENANCE, MECHANICAL  
DSS-3 CABLES

NO	EXPOSURE LOAD	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)			
				EXTREME	PER 1 YR.	CONTINUAL LONG TERM	PER 1 YR.
1	Tensile Load, Dynamic	<2000 N <sup>a</sup>	Installation	2000 N	1 Cycle		
2		<880 N <sup>b</sup>	Maintenance	880 N	1 Cycle		
3						240 N	1 min.
4	Impact	< 2 N·m	Maintenance Installation	2 N·m	1 Cycle <sup>c</sup>		
5	Crush	5300 N/50mm Length	Maintenance Installation	5300 N/50mm Length	1 Cycled		
6	Internal Abrasion	2000 N Tension 50mm dia. mandrel	Installation	2000 N on 50mm dia. mandrel	5 Cycle		

a - Weight of maximum cable length plus maximum attached transducer weight.

b - Hand hold support.

c - Specified in Underwriters Lab STD 44 (Par. 82).

d - Specified in Underwriters Lab STD 44 (Par. 81).

TABLE 9  
MISSION PROFILE - INSTALLATION AND MAINTENANCE, MECHANICAL  
DSS-4 CABLES

NO	EXPOSURE LOAD	EXPOSURE RANGE	OCCURANCE	DURATION (Time or Cycles)			
				EXTREME	PER 1 YR	CONTINUAL LONG TERM	PER 1 YR
1	Tensile Load, Dynamic	<490 N <sup>a</sup>	Installation	490 N	1 Cycle		
2		<880 N <sup>b</sup>	Maintenance	880 N	1 Cycle		
3						240 N	1 Min.
4	Impact	< 2 N·m	Maintenance Installation	2 N·m	1 Cycle <sup>c</sup>		
5	Crush	5300 N/50mm Length	Maintenance Installation	5300 N/50mm Length	1 Cycled		
6	Internal Abrasion	490 N Tension on 50mm dia. mandrel	Installation	490 N on 50mm dia. mandrel	5 Cycles		

a - Weight of maximum cable length plus maximum attached transducer weight.  
b - Hand hold support.  
c - Specified in Underwriters Lab STD 44 (Par.82).  
d - Specified in Underwriters Lab STD 44 (Par.81).

TABLE 10  
MISSION PROFILE - INSTALLATION AND MAINTENANCE, MECHANICAL  
FSS-2 CABLES

NO	EXPOSURE LOAD	EXPOSURE RANGE	OCCURRENCE	DURATION (Time or Cycles)		
				EXTREME	PER 1 YR.	CONTINUAL LONG TERM
1	Tensile Load, Dynamic	<860 N <sup>a</sup>	Installation	860 N	1 Cycle	
2		<880 N <sup>b</sup>	Maintenance	880 N	1 Cycle	
3						240 N
4	Impact	< 2 N·m	Maintenance Installation	2N·m	1 Cycle <sup>c</sup>	
5	Crush	5300 N/50mm Length	Maintenance Installation	5300 N/50mm Length	1 Cycled <sup>d</sup>	
6	Internal Abrasion	860 N Tension on 50mm dia. mandrel	Installation	860 N on 50mm dia. mandrel	5 Cycles	

a - Weight of maximum cable length plus maximum attached transducer weight

b - Hand hold support

c - Specified in Underwriters Lab STD 44 (Par 82).

d - Specified in Underwriters Lab STD 44 (Par 81).

TABLE 11

MISSION PROFILE - SSN SERVICE  
CABLES

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles)				COMPANION EXPOSURE
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature in Air	-55° to +60°C	Dockside	+60°C, 1.5 hr/day-270days	405 hr			Humidity Air Pollution
2				-30°C 12 hr/day - 30 days	360 hr			
3						+3° to +37°C for 270 days	6480 hr	
4			Arctic Surface	-55°C for 21 days	504 hr			
5	Temperature in Sea Water	-2° to +32°C	Tropical Ser.	+32°C for 90 days	2160 hr			Pressure Vibration
6			Arctic Service	-2°C for 90 days	2160 hr			
7						-1° to 11°C for 90 days	2160 hr	
8	Thermal Cycling	$\Delta T \leq 50^\circ C$	Dockside	$\Delta T = 50^\circ C$	270 cycles			Humidity Air Pollution
9						$\Delta T \leq 30^\circ C$	365 cycles	
10	Thermal shock	$\Delta T \leq 53^\circ C$	Diving-Tropic	$\Delta T \leq 28^\circ C$	30 cycles			
11			Diving-Arctic	$\Delta T \leq 53^\circ C$	3 cycles			
12	Pressure	100 to 4100 kPa	At Sea	4100 kPa day - 90 days	180 hr			Temperature Vibration
13						700 to 2100 kPa for 90 days	2160 hrs	
14	Pressure Cycling	100<P<4100 kPa	At Sea	100 to 4100kPa 2/day - 90days	180 cycles			
15						700 to 2100kPa 90days	180 cycles	
16	Humidity	-55° to +38°C Dew	Surface	38°C D.P. 24 hr/day -	6480 hr			Temperature Air
17						10° to 32°C D.P. - 270days	6480 hrs	
18	Air Pollution	0-500 psi <sup>a</sup>	Dockside	500 psi 8 hrs/day for 3 days <sup>c</sup>	24 hr			Temperature Humidity
19						200 + 50 psi 8 hrs/day 180 days	1440 hrs	
20	Vibration	Per MIL-STD-167-1 <sup>b</sup>	At Sea	Per MIL-STD-167-1	1 series			Temperature Pressure
21	Explosive Shock	Per CIPSB		Per CIPS	1 series			Pressure
22	Tensile Load, Static	Note d	All Service			Continuous Load per Note d	8640 hrs	Humidity Temperature Vibration Air Pollution

NOTES: a psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219

b Vibration and explosive shock as defined by specification due to lack of service data.

c Based on Los Angeles experience, 1975. Ozone is the major contaminant.

d Static stress based on 10 meters of unsupported cable. DSS-2 = 59 N, DSS-3 = 98 N, DSS-4 = 120 N, FSS-2 = 120 N.

TABLE 12

MISSION PROFILE - SSBN SERVICE  
CABLES

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles)				COMPANION EXPOSURE
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature Air	-55° to +60°C	Dockside	+60°C, 1.5 hr/day-40days	60 hrs			Humidity Pollution Air Pollution
2				-30°C 12 hr/day - 20 days	240 hrs			
3						+3° to 37°C for 60 days	1440 hr	
4			Arctic Surface	-55°C for 21 days	504 hrs			
5	Temperature Sea Water	-2° to +32°C	Tropical Service	+32°C for 270 days	6480 hrs	-1° to 11°C		Pressure
6			Arctic Service	-2°C for 270 days	6480 hrs			
7						1°C 11°C for 270 days	6480 hr	
8	Thermal Cycling	$\Delta T \leq 50^\circ C$	Dockside	$\Delta T = 50^\circ C$	60 cycles			Humidity Air Pollution
9						$\Delta T \leq 30^\circ C$	60 cycles	
10	Thermal Shock	$\Delta T \leq 53^\circ C$	Diving-Tropic	$\Delta T \leq 28^\circ C$	300 cycles			
11			Diving-Arctic	$\Delta T \leq 53^\circ C$	300 cycles			
12	Pressure	100 to 4100 kPa	At Sea	4100 kPa day - 300 days	7200 hrs			Temperature Vibration
13						700 to 2100kPa for 300 days	7200 hrs	
14	Pressure Cycling	100<P<4100 kPa	At Sea	100 to 4100kPa 2/day-300days	600 cycles			
15						700 to 2100kPa	600 cycles	
16	Humidity	-55° to +38°C Dew Point	Surface	38°C D.P. 24 hr/day - 60 days	1440 hr			Temperature Air Pollution
17						+10° to +32°C D.P. - 60days	1440 hr	
18	Air Pollution	0-500 psi <sup>a</sup>	Dockside	500 psi 8 hrs/day for 3 days <sup>c</sup>	24 hr			Temperature Humidity
19						200 + 50 psi 8 hrs/day for 60 days	48 hr	
20	Vibration	Per MIL-STD-167-1b	At Sea	Per MIL-STD - 167-1	1 series			Temperature Pressure
21	Explosive Shock	Per CIPSB		Per CIPS	1 series			Pressure
22	Tensile Load, Static	Note d	All Service			Continuous Load per Note d	8640 hr	Humidity Temperature Vibration Air Pollution

NOTES: a psi - Pollution Standard Index per Fed. Reg. Vol. 44, #219  
b Vibration and explosive shock as defined by specification due to lack of service data.  
c Based on Los Angeles experience, 1975. Ozone is the major contaminant.  
d Static stress based on 10 meters of unsupported cable. DSS-2 = 59 N, DSS-3 = 98 N, DSS-4 = 120 N, FSS-2 = 120 N.

TABLE 13

MISSION PROFILE - SURFACE SERVICE  
CABLES

NO.	EXPOSURE	RANGE OF EXPOSURE	OCCURANCE	DURATION OF EXPOSURE (hrs or cycles)				COMPANION EXPOSURE
				EXTREME	PER 1 YR.	CONTINUING LONG TERM	PER 1 YR.	
1	Temperature in Air	0° to +38°C	Dockside	0° C	4320 hr			Humidity Pollution
2				180 days				
3				+38°C	8640 hr			
4	Temperature in Sea Water	-2° to 32°C	Arctic	-2° C for 180 days	4320 hr			Pressure Vibration
5			Tropical	+32°C for 360 days	8640 hr			
6						0° to +30°C for 360 days	8640 hr	
7	Pressure	100 to 250 kPa	Service	250 kPa day 360 days	8640 hr			Temperature Vibration
8						100 to 250 kPa for 360 days	8640 hrs	
9	Humidity	0° to +38°C Dew Point	Service	38°C D.P. 360 days	8640 hr			Temperature Pollution
10						10° to +32°C D.P. - 360 days	8640 hr	
11	Air Pollution	0-500 psi <sup>a</sup>	Dockside	500 psi, 8 hrs/day for 3 days	24 hr			Temperature Humidity
12						200 + 50 psi 360 days	8640 hr	
13	Vibration	Per MIL-STD-167-1 <sup>b</sup>	At Sea	Per MIL-STD - 167-1	1 series			Temperature Pressure
14	Explosive Shock	Per CIPS <sup>b</sup>	At Sea	Per CIPS	1 series			Pressure
15	Tensile Load, Static	Note d	All Service			Continuous Load per Note d	8640 hr	Humidity

- NOTES: a psi - Pollution Standard Index per Fed. Reg. Vol. 44 #219  
b Vibration and explosive shock as defined by specification due to lack of service data.  
c Based on Los Angeles experience, 1975. Ozone is the major contaminant.  
d Static stress based on 10 meters of unsupported cable. DSS-2 = 6 Kg, DSS-3 = 10 Kg, DSS-4 = 12 Kg, FSS-2 = 12 Kg.

TABLE 14  
HYPOTHETICAL MAINTENANCE SCHEDULE

SHIP TYPE	DRYDOCK - RESTRICTED AVAILABILITY		DRYDOCK - OVERHAUL	
	INTERVAL	TIME IN DRYDOCK	INTERVAL	TIME IN DRYDOCK
SSN	22 - 24 Months	45 Days	5 1/2 - 7 Years	6 - 10 Months
SSBN	22 - 24 Months	45 Days	5 1/2 - 7 Years	6 - 10 Months
SURFACE	-----	-----	3 - 4 Years	28 - 45 Days



## 6.0 TEST PLAN

6.1 Cable Selection

Ten cable designs were selected for evaluation, five shielded and five unshielded, and were examined, dissected and the internal components measured. A list of the cables and physical description of each is given in Table 15.

Cables were selected according to their current or proposed use in the fleet. Shielded cables include DSS-2, DSS-3 (single and double jacket), DSS-4 and FSS-2 made to MIL-C-915. The unshielded cables include TRIDENT specification polyethylene cable, DSU-2 and DSU-3 made to a proposed specification, and unshielded DSS-2 and butyl cable made to in-house descriptions. Figures 2-4 are illustrations of the cable samples.

6.2 Test Selection

Since the mechanical attributes of shielded and unshielded cable were of primary interest in this program, the Mission Profiles were reviewed for data indicating mechanical stress to the cable. The Installation and Maintenance profiles showed that tensile strength, crush and flexure resistance, and static stress creep were mechanical stresses influencing cable performance. Cables, DSS-3 in particular, are used in hull stuffing tubes and must perform satisfactorily in this service.

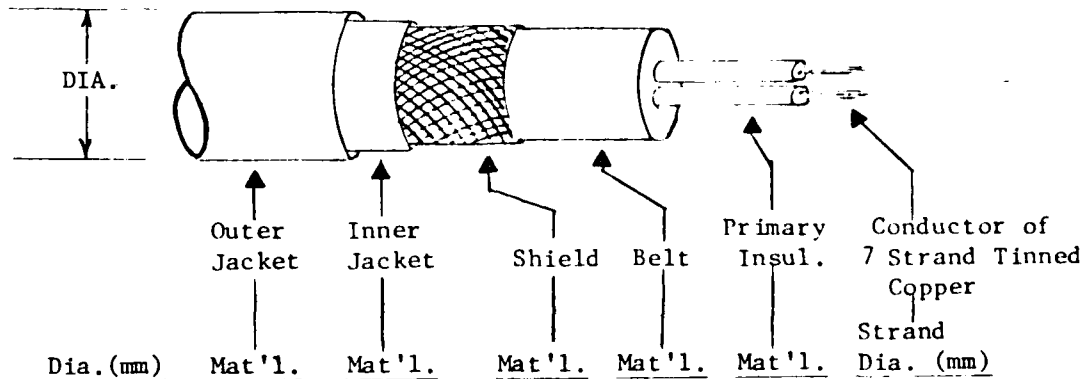
Standard tests were reviewed for those applicable to cable performance. The sources reviewed included American Society for Testing and Materials (ASTM), Underwriter Laboratory, military and federal specifications and other industrial sources. Table 16 lists the tests selected for this program, the measurements to be made, and the test objectives.

TABLE 15  
CABLE DESCRIPTION

CABLE	TYPE	MASS (kg/km)	CABLE DIA. (mm)	JACKET THICKNESS (mm)	JACKET LAYERS	BELT DIA. (mm)	BELT THICKNESS (mm)	DIA. (mm)	NO.	INSULATION	CONDUCTORS THICKNESS (mm)	COLOR	STRAND DIA. (mm)	COMMENTS
DSS-2 Special	unshielded	3.3	8.89	2.16-3.68	1	---	---	2.79	2	Single Rubber	0.63	B&W	0.41	Conductors loose in belt, will slide under tension.
DSS-2	shielded	4.2	10.16	1.52	2	6.72	0.76-1.65	2.79	2	Single Rubber	0.63	B&W	0.41	Double jacket separates easily, shield is tightly adhered to inner jacket. Conductors separate easily.
DSU-2	unshielded	3.5	9.91	1.90-4.19	2	---	---	2.54	2	Rubber w/ plastic sheath	0.63	B&W	0.38	Double jacket separates easily, jacket separates from belt easily, conductors loose in belt.
DSS-3 Double Jacket	shielded	7.2	12.70	2.16	2	8.25	0.63-3.30	3.56	2	Single Rubber	0.99	B&W	0.51	Double jacket separates easily, shield removed easily, conduc- tors separate easily.
DSS-3 Single Jacket	shielded	7.2	12.70	2.16	1	8.25	0.89-3.43	3.81	2	Single Rubber	0.89-1.14	B&W	0.51	Jacket tightly adhered to belt, conductors loose in belt.
DSU-3	unshielded	5.4	12.70	2.41	1	8.00	1.78-3.43	3.05	2	Single Rubber	0.76	B&W	0.46	Jacket tightly adhered to belt, conductors loose in belt.
DSS-4	shielded	8.4	12.70	1.78	2	8.25	0.76-3.68	3.81	2	Rubber w/ plastic sheath	0.91	B&W	0.61	Double jacket separates easily, shield separates easily, con- ductors separate easily.
FSS-2	shielded	8.4	12.70	2.29	2	8.25	0.89-3.43	2.54	4	Single Rubber	0.63	B&W	0.41	Double jacket separates easily, shield separates easily, con- ductors adhered to belt.
BUTYL	unshielded	5.3	12.70	2.29	1	8.25	0.63-1.90	3.81	2	Single Rubber	0.63-1.27	B&W	0.51	Jacket separates from belt easily, conductors loose in belt.
TRIUMPH Polyethylene	unshielded	1.5	7.11	1.65-3.05	1	---	---	1.90	2	Double Plastic	0.28	Clear over B&W	0.30	Jacket hard and tight over conductors.

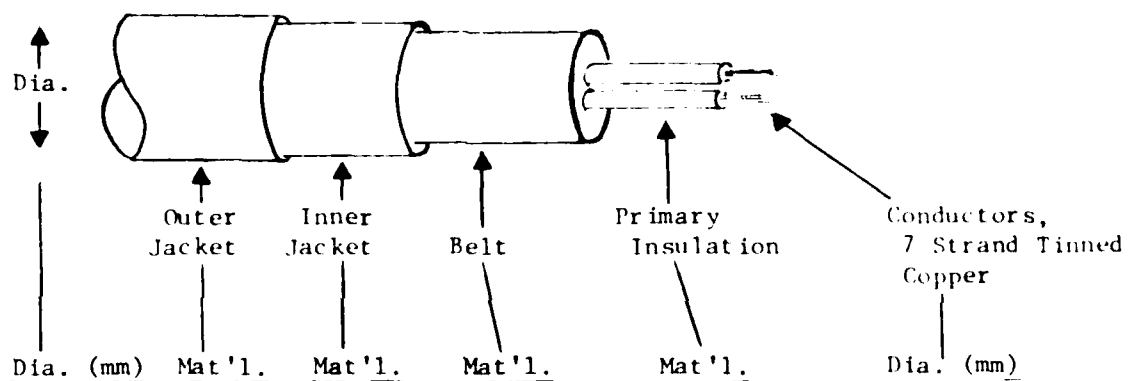
\*Seven strands per conductor.

FIGURE 2  
ILLUSTRATION OF MIL-C-915/8 CABLE



	Dia. (mm)	Outer Jacket	Inner Jacket	Shield	Belt	Primary Insul.	Conductor of 7 Strand Tinned Copper Strand Dia. (mm)
		Mat'l.	Mat'l.	Mat'l.	Mat'l.	Mat'l.	
DSS-2/E	10.16	Neoprene	Synthetic Rubber	Tinned Copper	Synth. Rubber	Synth. Rubber	0.41
DSS-3/A	12.70	Neoprene	None		Synth. Rubber	Synth. Rubber	0.51
DSS-3/E	12.70	Neoprene	Synthetic Rubber		Synth. Rubber	Synth. Rubber	0.51
DSS-4/E	12.70	Neoprene	Synthetic Rubber		Synth. Rubber	Synth. Rubber	0.61
FSS-2/E	12.70	Neoprene	Synthetic Rubber		Synth. Rubber	Synth. Rubber	0.41

FIGURE 3  
ILLUSTRATION OF UNSHIELDED DSU-TYPE CABLE



	Dia. (mm)	Mat '1.	Mat '1.	Mat '1.	Mat '1.	Dia. (mm)
Special DSS-2	8.89	Neoprene	None	Synthetic Rubber	Synthetic Rubber	0.41
DSU-2	9.91	Neoprene	Synth. Rubb.	Synthetic Rubber	Synthetic Rubber	0.38
DSU-3	12.70	Neoprene	None	Synthetic Rubber	Synthetic Rubber	0.46
Butyl-3	12.70	Butyl	None	Synthetic Rubber	Synthetic Rubber	0.51

FIGURE 4  
ILLUSTRATION OF TRIDENT POLYETHYLENE CABLE

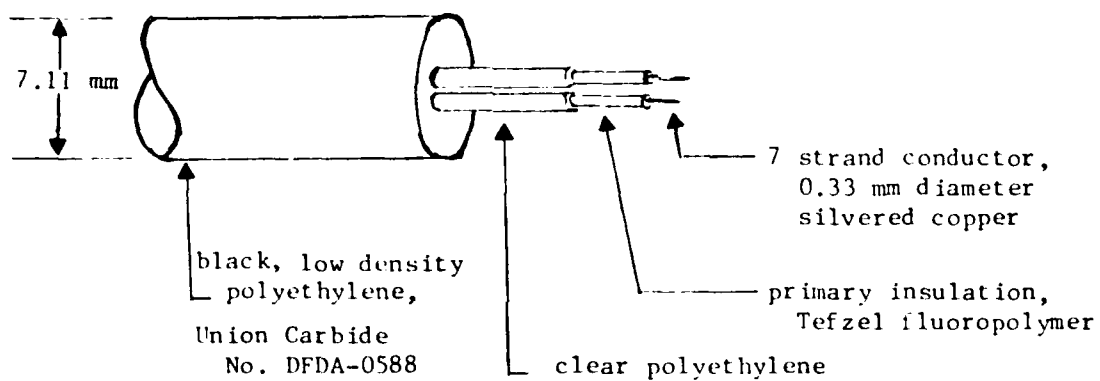


TABLE 16  
CABLE TEST PLAN

TEST	PROCEDURE	MISSION PROFILE REFERENCE	TEST SAMPLES	MEASUREMENTS, OBSERVATIONS	OBJECTIVE
Tensile Breaking Strength	ASTM-D-412 ASTM-D-470	Installation & Maintenance	Cable & Components, All Samples	Ultimate Strength, Elongation, Order of Component Break, Electrical Continuity	Ultimate Strength, Resistance to Maintenance and Installation Abuse
Flexural Abrasion	DuPont Design	Installation & Maintenance	Cables, All Samples	Stress, Cycles, Elongation, Continuity Resistance Breakdown (Megohm) Electrical Insulation	Fatigue Endurance, Insulation Degrada- tion Due to Internal Conductor or Shield Break
Breaking Bend Strength	----	Installation & Maintenance	Cables, All Samples	Ultimate Strength, Elongation, Mode of Electrical Failure (Open or Short)	Mode of Electrical Failure Ultimate Strength Due to Tension over a Radius
Crush Resistance	ANSI/UL STD.44-1977	Installation & Maintenance	Cables, All Samples	Force to Failure Mode of Electrical Failure (Open or Short)	Resistance to Crushing Force, Mode of Failure
Performance Hull Stuffing Tube	----	Service	Cables, (DSS-3, DSU-3)	Electrical Characteristics Physical Dimensions, Grommet Compression, Leakage, Cable Movement Permanent Set in Cables	Movement, Leakage, Electrical characteristics in stuffing tube
Creep in Static	----	Installation & Maintenance,	Cables, All Samples	Stress, Time, Elongation Electrical Characteristics	Failure due to creep

## 7.0 TESTS RESULTS

7.1 Tensile Properties

The tensile properties of the complete cables and of the cable components were measured following the testing parameters shown in Table 17. All complete cables, cables less jacket and cables less jacket and shield were fixtured on a 102 mm diameter capstan grip for testing as shown in Figure 5. The individual components removed from the cable were cut into dogbone tensile specimens using ASTM-D-412 Die C. Wedge grips were used to hold elastomer samples and to hold the cut elastomer and conductor samples for tensile testing.

Tensile results for the cable components are shown in Table 18. Maximum force applied to each sample and the sample elongation at maximum force is reported and in all cable samples, maximum force was obtained at the point of first conductor break. Stress for the elastomer dogbone samples was calculated on the basis of cross sectional area of the sample. The jacket on the unshielded DSS-2 and on the DSU-2 did not separate from the belt, and therefore, a cable strength less jacket was not measured. Also, the TRIDENT polyethylene cable does not have a separate jacket and, therefore, jacket data are not reported.

Cable tensile properties are given in Table 19. Three samples of each cable type were tested and for all cables, the maximum force was obtained when a conductor broke. The elongation at maximum force is also reported. The yield strength was calculated for each cable and is included in the data. Figure 6 shows a recorded force-elongation plot for DSS-3 cable and and Figure 7 the recorded data for DSU-3 cable. These curves were typical of those obtained for other cable sizes.

TABLE 17  
TENSILE TEST PARAMETERS

Test No.	Test Description	Sample	Strain Rate (mm/min)	Gage Length (mm)
1	Tensile strength, cable, 102 mm diameter Capstan grips	Cable and components, 1.83m sample	51	102
2	Tensile strength, wire, wedge grips	Wire sample 152 mm sample	51	51
3	Tensile strength, insulation, wedge grips	Elastomer insulation cut to ASTM-D-412, Die C	51	51



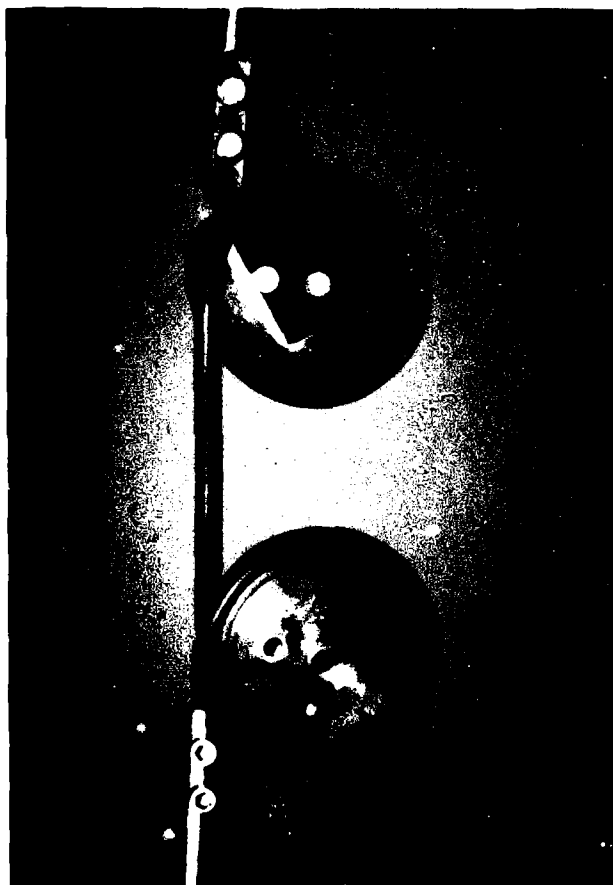


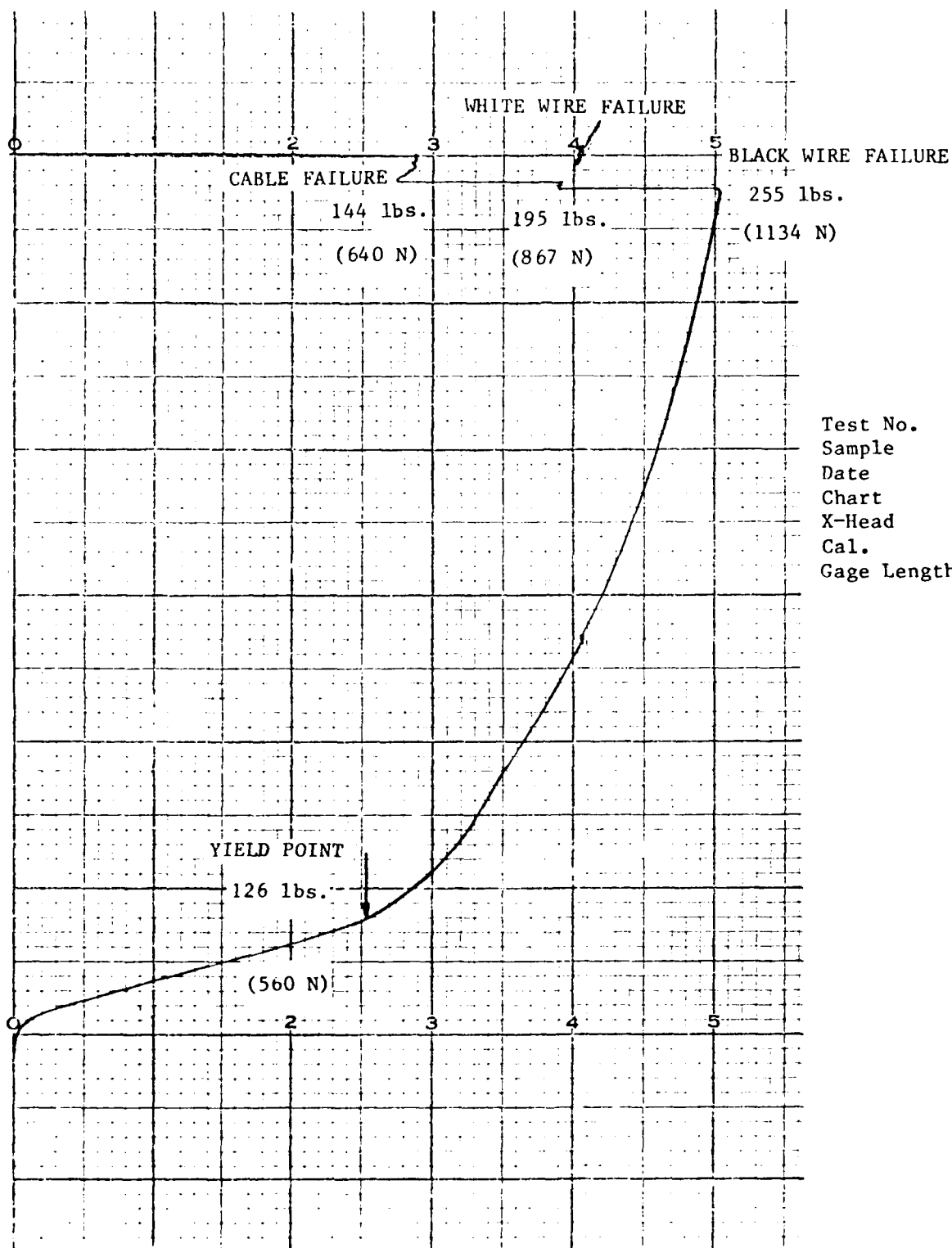
FIGURE 5  
Cable Tensile Test Fixture

TABLE 18 - CABLE COMPONENT TENSILE PROPERTIES

CABLE TYPE	COMPLETE CABLE			LESS JACKET			LESS JACKET SHIELD			CONDUCTOR W/INSULATION			COMPONENT STRENGTH MPa	
	Max Force N	Elong. %		Max Force N	Elong. %		Max Force N	Elong. %		Max Force N	Elong. %		Jacket	Belt
DSS-2 Unshielded	520	46		---	---		---	---		230	7		11.0	---
DSS-2	620	76		570	47		460	56		210	7		9.0	5.9
DSU-2	500	50		---	---		---	---		210	7		13.1	6.0
DSS-3 Double Jacket	1140	70		990	48		710	46		340	19		8.3	6.1
DSS-3 Single Jacket	1130	77		1010	68		720	38		340	19		9.0	6.7
DSU-3	860	56		680	30		---	---		370	16		12.4	16.5
DSS-4	1540	84		1490	56		1200	54		590	16		7.6	8.3
FSS-2	1320	57		1230	51		900	36		230	15		6.3	9.0
BUTYL Size 3	760	73		730	64		---	---		340	13		11.0	10.3
TRIDENT Polyethylene	800	49		---	---		---	---		280	12		---	---

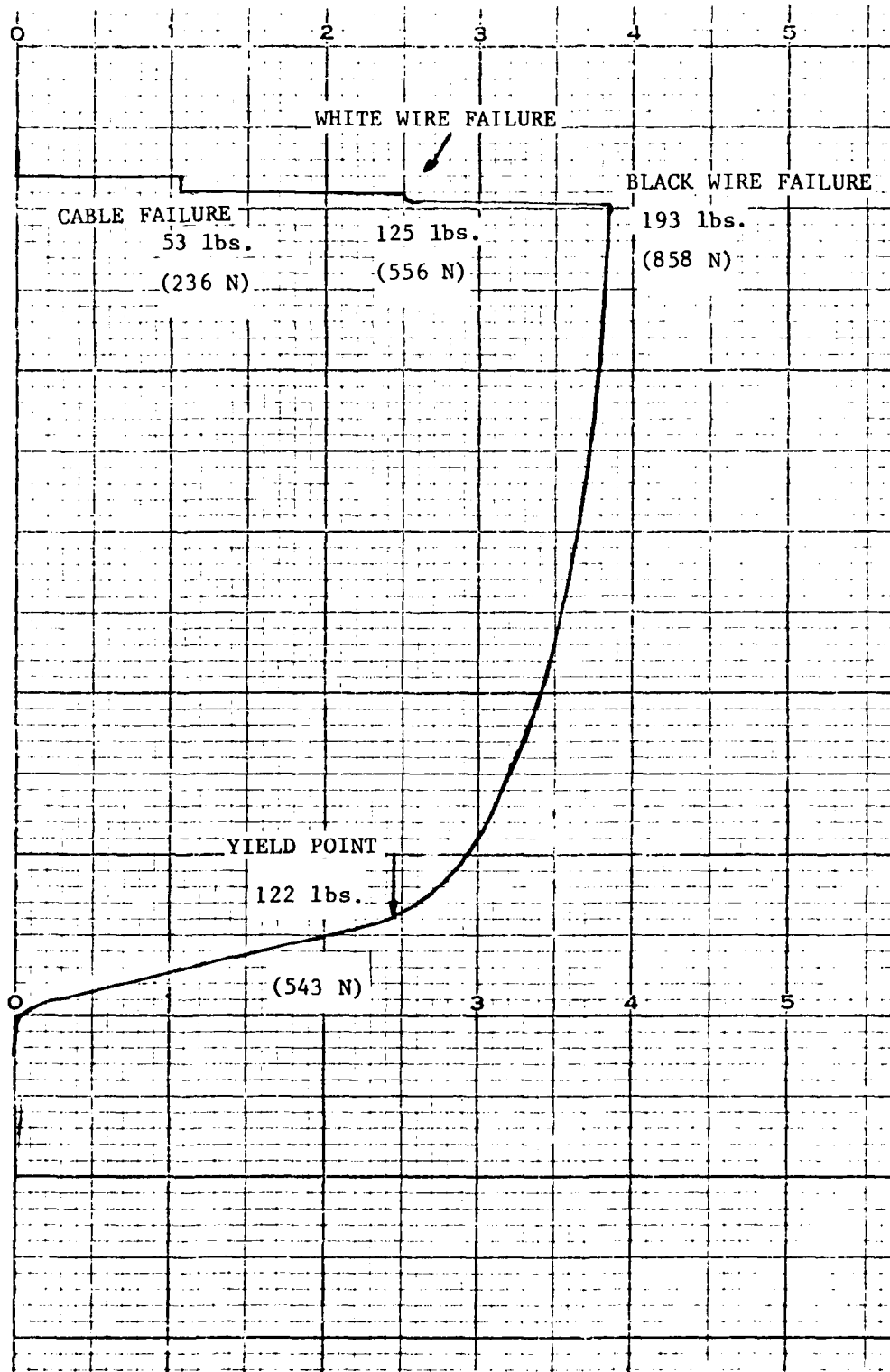
TABLE 19  
CABLE TENSILE - PROPERTIES

SAMPLE TYPE	Maximum Force (N)			ELONGATION	YIELD STRENGTH (N) 1% OFFSET
	1	2	3		
DSS-2 Unshielded	510	510	530	520	46%
DSS-2	610	650	550	600	76%
DSU-2	520	490	500	500	50%
DSS-3 Double Jacket	1130	1110	1170	1130	70%
DSS-3 Single Jacket	1130	1130	1110	1120	77%
DSU-3	860	840	870	1860	56%
DSS-4	1540	1570	1570	1550	84%
FSS-2	1320	1330	1310	1320	57%
BUTYL Size 3	750	740	790	760	73%
TRIDENT Polyethylene	870	770	750	800	49%
					620



Test No. 133-40-4  
Sample 133-6-4 (DSS-3)  
Date 7/30/79  
Chart 2 in./min.  
X-Head 1 in./min.  
Cal. 0-500 lb F.S.  
Gage Length 6 in.

FIGURE 6  
TENSILE LOAD CHART  
DSS-3 CABLE



Test No. 133-41-10  
Sample 133-23-11  
Date 7/30/79  
Chart 2 in./min.  
X-Head 1 in./min.  
Cal. 0-500 lb F.S  
Gage Length 6 in.

FIGURE 7  
TENSILE LOAD CHART  
DSU-3 CABLE

## 7.2 Flexural Abrasion

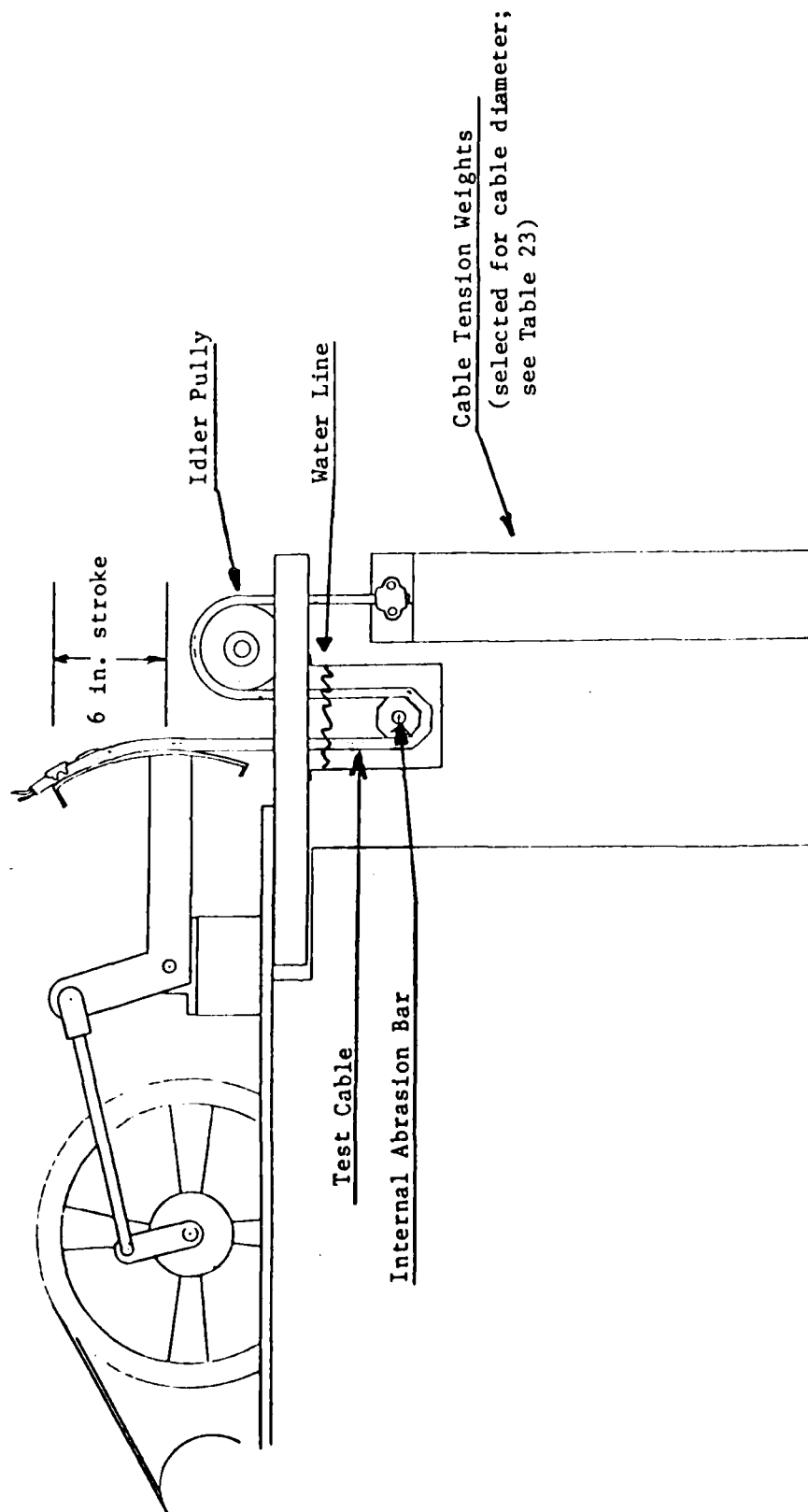
A flexural abrasion test was designed to fatigue the metal components of the cables while under stress. The objective of this test was to induce failure of the shield wires and measure any penetration of the jacket or primary insulation by broken wires through monitoring electrical continuity of the wires to ground.

The apparatus used for this test was based on a design developed by DuPont for evaluating internal abrasion of Kevlar electro-mechanical cables. The test and fixture were presented by DuPont at the February, 1979 Marine Technology Society Cables and Connectors workshop in San Diego, and no formal specification is known to exist. The equipment is schematically shown in Figure 8 and consists of a 50.8 mm diameter octagonal mandrel submerged in a water bath, a drive system to move test cables over the mandrel and a tensioning system to stress the cables while in motion. Figure 9 shows cables attached to the apparatus.

In operation, the cables were individually tensioned using dead weights, bent 180° around the octagonal bar and oscillated at 30 cycles/minute with a 127mm stroke length. The continuity of the conductors was monitored during the test. Insulation resistance between the conductors and shielding and between the conductors, shield and water was also monitored to detect possible penetration of the insulation by broken wires. Failure was defined as shield or conductor discontinuity or a short indicating penetration of the insulation.

Table 20 shows the results of the test. The number of cycles at failure is noted along with the increase in cable length. The failure mode in each failed cable was an open conductor. Shorts to ground or degradation of insulation resistance was not found, indicating that insulation was not punctured by broken wires. Two cable samples, FSS-2 and TRIDENT Polyethylene did not fail and were

FIGURE 8  
FLEXURAL ABRASION TESTER



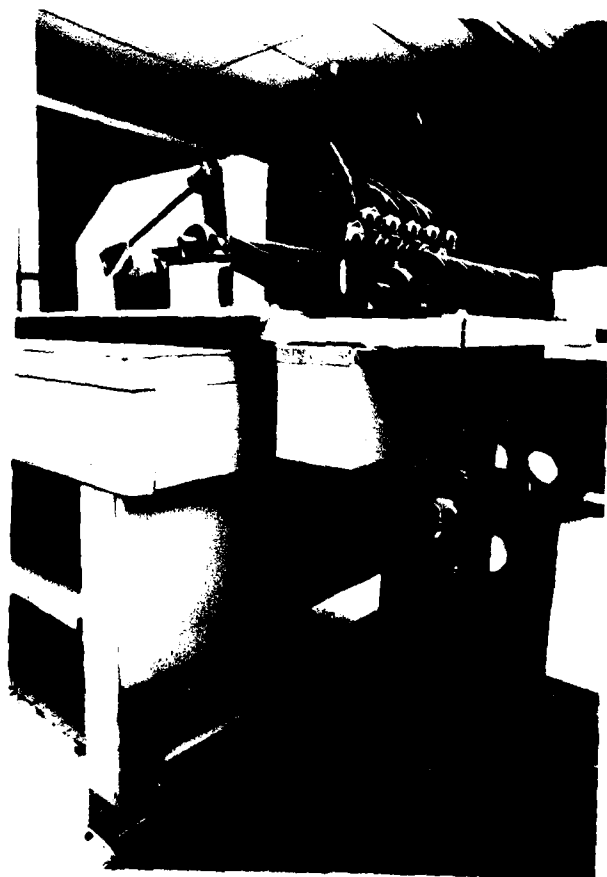


FIGURE 9  
Flexural Abrasion Test Fixture



TABLE 20  
FLEXURAL ABRASION TEST SUMMARY

Sample Number	Type	Cable Stress (kPa)	Cycles to Failure	Elongation at Failure (%)	Failure Mode
1	DSS-2 Unshielded	600	1900	2.8	Open Conductor
2	DSS-2	470	13000	2.8	Open Conductor
3	DSU-2	490	10000	1.4	Open Conductor
4	DSS-3 Double Jacket	440	15000	2.1	Open Conductor
5	DSS-3 Single Jacket	440	11000	1.4	Open Conductor
6	DSU-3	440	8800	0.7	Open Conductor
7	DSS-4	440	11000	1.4	Open Conductor
8	FSS-2	440	>20000	1.4	No Failure
9	BUTYL Size 3	440	6700	3.5	Open In
10	TRIDENT Polyethylene	570	>20000	<0.7	No Failure

removed from the test after 20,000 cycles. All test cables were dissected at the conclusion of the test to confirm failure modes and the observations made are summarized in Table 21.

### 7.3 Bend Tensile Strength

Samples of DSS-3 and DSU-3 cable were tested in tension around a 51 mm diameter mandrel to determine the effect of compressive force in conjunction with a tensile force on cable failure characteristics. The ends of the sample were fixtured to a 102 mm diameter capstan grip with the center supported by the mandrel. The samples were tensioned at a rate of 51 mm/minute while the continuity of the conductors and the resistance between conductors and shield was monitored. Applied force was continuously recorded during the test.

Three samples of both cable types were tested and test results are summarized in Table 22. The location of conductor failure was between the mandrel and the grip, and no damage was observed in the cables in contact with the mandrel.

A separate sample of DSU-3 was tested in the same fixture and mutual capacitance of the conductors monitored. Capacitance as a function of applied force is plotted in Figure 10.

### 7.4 Crush Resistance

The resistance of cable to crush was measured following the test procedures outlined in ANSI/UL Standard 44-1977, PAR 81. This test requires that a cable sample be placed between two 51 mm wide parallel steel plates and a force applied to plates at a rate of 13 mm per minute. The compressive force was continuously recorded and electrical continuity between conductors and steel plates monitored.

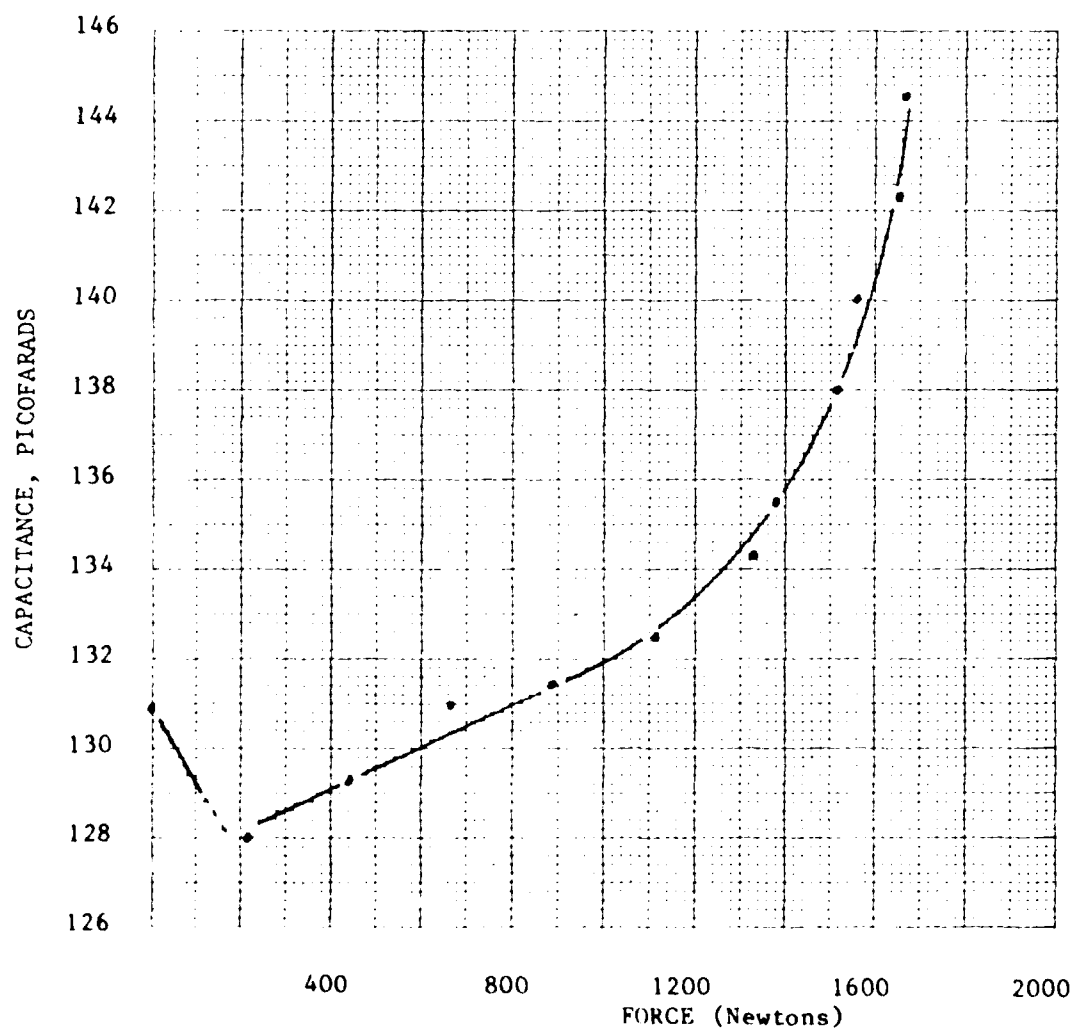
TABLE 21  
FLEXURAL ABRASION TEST OBSERVATIONS

Sample Number	Type	Observation
1	DSS-2 Unshielded	Both conductors separated.
2	DSS-2	Shield intact, both conductors separated.
3	DSU-2	Both conductors separated.
4	DSS-3 Double Jacket	Shield separated 50%, no shield penetration of insulation. Both conductors separated.
5	DSS-3 Single Jacket	Shield intact, both conductors separated.
6	DSU-3	Both conductors separated.
7	DSS-4	Shield intact, both conductors separated.
8	FSS-2	Cable intact, no conductor or shield breakage.
9	BUTYL Size 3	Both conductors separated.
10	TRIDENT Polyethylene	Cable exterior roughened, no internal damage observed.

TABLE 22  
TENSILE BEND TEST SUMMARY

CABLE TYPE	AVERAGE FORCE TO FAILURE (N)	FORCE PER CABLE (N)	FAILURE ANALYSIS
DSS-3 Double Jacket	2222	1111	Conductor broken between mandrel and grip, no damage observed over mandrel, 40-50% shield broken, separation of 1st and 2nd jacket observed.
DSU-3	1713	857	Conductor broken between mandrel and grip, no damage observed over mandrel, separation of jacket and belt observed.

FIGURE 10



CAPACITANCE CHANGE  
with  
Tensile Force

CABLE TYPE - DSU-3

TOTAL LENGTH - 1.5 m

Two Lengths in Tension Around a 50 mm Dia. Mandrel

Test results are given in Table 23 and dissection of samples after testing confirmed the indicated failure modes. In no instance did a conductor or shield short to the compression plates before the conductors shorted to each other. In case of TRIDENT polyethylene cable, the conductors parted and did not short.

#### 7.5 Hull Stuffing Tube Performance

The performance of DSS-3 and DSU-3 cables was evaluated in a hull stuffing tube made to NAVSEA DWG. No. 900-56202-F-1197101 (Stuffing Tube PP for SS and TSP type cable). This assembly is a compression grommet seal device used as a cable feed-through in ship hulls. The test cables were assembled in the stuffing tube according to NAVSEA procedures and subjected to three series of hydrostatic pressure sequences as shown in Table 24. Criteria for evaluation was measurement of cable movement during or between test sequences, water leakage through the stuffing tube and electrical characteristics of the conductors and shield.

Three samples of DSS-3 and four samples of DSU-3 cable were tested. Table 4 summarizes the results through the three complete test sequences. Insulation resistance of the conductors and shield was measured at the end of each complete sequence as was cable movement through the fitting. Sample Numbers 4 and 5 of DSU-3 cable were removed after the first test sequence because they shipped too far in the stuffing tube during the first pressure test sequence. None of the cables showed electrical failure. All cable samples were dissected at the conclusion of the test. The shielded cables showed permanent deformation of the shield and partial shield breakage. Defects or permanent set were not observed in the non-shielded cables.

#### 7.6 Static Tension

All cable samples were subjected to a static tensile load simulating conditions that might exist when a vertical length of cable is hung unsecured. The

TABLE 23  
CABLE CRUSH - TEST SUMMARY

CABLE TYPE	CABLE DIAMETER (mm)	COMPRESSION AT FAILURE (mm)	% COMPRESSION	LOAD TO FAILURE (N)				FAILURE MODE
				1	2	3	AVG	
DSS-2 Unshielded	8.89	4.1	50	1660	2260	2660	2200	Conductor-conductor short
DSS-2	10.16	5.2	51	6060	6070	5250	5790	Conductor-conductor short
DSU-2	9.91	5.6	56	4440	5340	5340	5040	Conductor-conductor short
DSS-3 Double Jacket	12.70	6.9	54	6110	7110	7110	6770	Conductor-conductor short
DSS-3 Single Jacket	12.70	6.9	55	6220	6670	6670	6520	Conductor-conductor short
DSU-3	12.70	6.9	54	6220	6670	5340	6070	Conductor-conductor short
DSS-4	12.70	6.7	53	6330	5550	5440	5780	Conductor-conductor short
FSS-2	12.70	7.5	59	9780	8890	11110	9930	Conductor-conductor short
BUTYL Size 3	12.70	5.4	43	1770	1770	1770	1770	Conductor-conductor short
TRIDENT Polyethylene	7.11	5.7	78	26600	25400	28900	27000	Open conductor

TABLE 24  
STUFFING TUBE TEST SEQUENCE

Cycle	Operation
1	Pressurize 0-1.82 MPa - repeat for 20 cycles
2	Pressurize 0-3.55 MPa - repeat for 20 cycles
3	Pressurize 0-6.99 MPa - repeat for 20 cycles
4	Pressurize 0-10.44 MPa - repeat for 20 cycles
5	Pressurize 0-13.89 MPa - repeat for 20 cycles
6	Pressurize 0-1.82 MPa - hold at 1.72 MPa for 8 hrs.
7	Reduce pressure to 0.1 MPa - hold at 0.1 MPa for 8 hrs.



load used for this test was the same as the load used for flexural abrasion testing. A sample length was 305 mm and was monitored for elongation during the test. The test was terminated after 30 days and the test results are shown in Table 25.

TABLE 25  
CABLE ELONGATION IN STATIC TENSION

SAMPLE NO.	CABLE	LOAD (kPa)	TIME	ELONGATION % *
1	DSS-2 Unshielded	607	30 Days	<1.0
2	DSS-2	469	30 Days	<1.0
3	DSU-2	489	30 Days	<1.0
4	DSS-3 Double Jacket	441	30 Days	<1.0
5	DSS-3 Single Jacket	441	30 Days	<1.0
6	DSU-3	441	30 Days	<1.0
7	DSS-4	441	30 Days	<1.0
8	FSS-2	441	30 Days	<1.0
9	BUTYL Size 3	441	30 Days	<1.0
10	TRIDENT Polyethylene	565	30 Days	<1.0

\*All samples elongated 3.17 mm per 305 mm gage length.